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To the Graduate Council:

I am submitting herewith a thesis written by Alexandra Chelsea Romano entitled "Infant Object Recognition: Two- and Three-Dimensional Visual Processing." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Psychology.

Greg D. Reynolds, Major Professor

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Infant Object Recognition: Two- and Three-Dimensional Visual Processing

A Thesis Presented for the

Master of Arts

Degree

The University of Tennessee, Knoxville

Alexandra Chelsea Romano

August 2017

ACKNOWLEDGEMENTS

My sincerest thanks to and gratitude for my advisor, Dr. Greg Reynolds, as well as my committee members Dr. Daniela Corbetta and Dr. Jenn Bolden. Thank you to Kelly Roth and Alexa Stumpe for their assistance. Also, thank you to the many undergraduate research assistants who have contributed their time and effort.

ABSTRACT

Visual attention and recognition memory in infancy are highly dependent on the type of stimulus the infant is familiarized to and the conditions of familiarization. For example, in studies that initially exposed infants to test stimuli in laboratory settings (e.g., Courchesne, Ganz, & Norcia, 1981; Reynolds & Richards, 2005), the Negative Central (Nc) event-related potential (ERP) component associated with infant visual attention has shown greater amplitude for novel compared to familiar stimuli. Conversely, when initial stimulus exposure occurred outside of the laboratory and the stimulus was highly familiar, studies have shown greater amplitude Nc to familiar compared to novel stimuli (e.g., de Haan & Nelson, 1997, 1999; Moulson, Shannon, & Nelson, 2011). This study investigated differences in attention and recognition memory for 6-month-old infants familiarized with an object in either a 2-D and 3-D controlled familiarization in a laboratory setting. Following familiarization, attention and recognition memory were measured during a standard ERP recognition memory procedure using 2-D photographic images of the familiar and novel objects. The Nc ERP component was used as a measure of visual attention, and the Late Slow Wave (LSW) ERP component as a measure of recognition memory. There was increased Nc ERP amplitude to the novel stimulus among infants in the 2-D condition. However, no significant differences in Nc amplitude based on stimulus type were found for infants in the 3-D condition. Analysis of the LSW showed a main effect for stimulus type, with greater amplitude positive LSW to the novel stimuli across familiarization conditions and electrode sites. These results indicate that familiarization with an object in 2-D or 3-D has differential effects on the salience hierarchy of familiar compared to novel stimuli in subsequent testing. At the same time, infants were able to fully process the familiar object under both familiarization conditions.

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CHAPTER I

INTRODUCTION

Visual attention and recognition memory are complex, fundamental cognitive processes that undergo much development during infancy. Attention is guided towards stimuli that are meaningful or possess specific attention-grabbing perceptual features, thus making these stimuli more salient. Selective attention serves to focus an organism's perceptual and cognitive processing on salient stimuli or salient stimulus properties at the expense of other stimuli in the surrounding environment. There is also evidence to support that attention to a stimulus is closely tied to later recognition memory (Reynolds, Courage, & Richards, 2010; Richards, 2003). These findings indicate visual recognition memory for a given stimulus is heavily influenced by attention during initial exposure. For example, past research has shown differential effects on infant event-related potential (ERP) components associated with visual attention and recognition memory depending on the type of familiarization procedure used, and characteristics of the test stimuli (e.g., Carver, Meltzoff & Dawson, 2006; Courchesne et al., 1981; de Haan & Nelson, 1997, 1999; Moulson et al., 2011; Reynolds et al., 2005, 2010). Therefore, initial exposure conditions during familiarization have a profound impact on how infants attend to and process stimuli during laboratory testing.

The purpose of this study was to shed light on how the experience of familiarization with a two-dimensional (2-D) photograph of an object affects neural processes associated with visual attention and recognition memory in 6-month-old infants compared to familiarization with a three-dimensional (3-D) object. More specifically, the aim was to investigate the effects of controlled laboratory familiarization to an object in either 2-D or 3-D exposure conditions on ERP correlates of attention and recognition memory with 6-month-old infants. This study

expands on previous literature that shows contrasting findings on the impact of familiarity on Negative central (Nc) event-related potential (ERP) amplitude depending on the context in which familiarization occurred (Courchesne, Ganz, & Norcia, 1981; de Haan & Nelson, 1997, 1999; Moulson, Shannon, & Nelson, 2011; Reynolds & Richards, 2005). Across studies, when the familiar stimuli used during testing were the mother's face or a favorite toy from home, infants demonstrated greater Nc amplitude (indicative of greater attention) to familiar stimuli in comparison to novel stimuli (Moulson et al., 2011; de Haan & Nelson, 1997, 1999). However, when briefly familiarized in the lab with previously novel 2-D stimuli prior to testing, infants demonstrated greater amplitude Nc to novel compared to familiar stimuli (Courchesne et al., 1981; Moulson et al., 2011; Reynolds & Richards, 2005). The enhanced attention to highly familiar stimuli from home could be due to a number of factors, including: the emotional valence tied to the mother's face or a toy from home, extensive familiarization at home in comparison to brief familiarization in the lab, or familiarization in 3-D in comparison to familiarization in 2-D.

This study was designed to examine the effects of controlled laboratory familiarization in either 2-D or 3-D exposure conditions on ERP correlates of attention and recognition memory in 6-month-old infants. In addition to analyzing the Nc component, the late slow wave (LSW) was analyzed to allow for examining whether any differential effects of 2-D or 3-D familiarization on visual processing occur at the level of attention (Nc), recognition memory (LSW), or both. In the sections that follow, I review relevant research and theory, beginning with a selected review of findings from behavioral research examining relations between infant visual attention, visual processing, and recognition memory. I subsequently review the most relevant infant ERP research before presenting the primary goals and hypotheses for the current study.

Infant Research on 2-D and 3-D Visual Processing

Visual processing and recognition memory are strongly dependent on amount of exposure an infant is given to a stimulus during familiarization (Rose, Gottfried, Melloy-Carminar, & Bridger, 1982). However, other factors such as stimulus complexity or feature saliency also influence attention to the stimulus or depth of processing. It is possible that visual processing and recognition memory might differ when infants are familiarized to a 2-D (picture of an object) vs. a 3-D object (Carver, Meltzoff, & Dawson, 2006). Though humans exist in a world comprised of more than two dimensions, much of the current research on recognition memory in infancy has been limited to examining infant participants' perceptual responsiveness to 2-D visual patterns or 2-D pictures of objects or faces. Therefore, research incorporating familiarization to 3-D stimuli is needed to complement previous research using 2-D stimuli, as 3-D stimuli would increase ecological validity.

Behavioral Research

Behavioral work has provided evidence of differences in visual processing of stimuli in either 2-D or 3-D. For example, Ruff, Kohler, and Haupt (1976) compared 2-D and 3-D visual processing with 3- and 5-month-old infants. Infants were familiarized over six trials to either a 3-D object or a 2-D representational photograph of the object. During testing, infants were presented with two paired-comparison trials of either the familiar or novel object to assess infant recognition memory for the previously viewed object or photograph. Only the 5-month-old infants showed evidence of novelty preference and recognition memory for the familiar stimulus, and only within the 3-D object condition. Since novelty preference (indicative of adequate visual

processing for demonstrating recognition memory of the familiar stimulus) was only evident in the 3-D familiarization condition, these results indicate 3-D objects were more efficiently processed than 2-D pictures of the objects in this study.

In another study comparing processing of visual stimuli in 2-D or 3-D, Pierroutsakos and DeLoache (2014) first presented 9-month-old infants with 2-D pictures of objects with varying degrees of realistic representations of their 3-D object counterparts. Infants were found to manually interact with the 2-D image more when the 2-D image was more realistic in appearance. The authors then manipulated the images to test whether the infants were merely responding to the contrast of the images on the page rather than an increased interpretation of the image as the physical object. Infants were presented with images of objects with a high-contrast oval surrounding the object. Even with the oval, infants continued to manually explore the object image. The authors concluded that 9-month-old infants have difficulty fully comprehending 2-D images of objects as representations of 3-D objects. In other words, infants were able to visually process the 2-D stimuli, including the depth cues within the image. However, the infants were unable to understand the visual information that would indicate that the image is not the object it represents, and therefore viewed the image and object as one in the same (Pierroutsakos & DeLoache, 2003).

Yonas and colleagues (Yonas, Granrud, Chov, & Alexander, 2005) offered an alternative explanation to Pierroutsakos and DeLoache (2003), stating that the manual behaviors infants exhibited towards photographs could be explained as surface exploration of the pictures rather than attempts to pick up actual objects. Yonas and colleagues (2005) examined this by recording 9-month-old infants' interactive behavior when exposed to three-dimensional objects, photographs objects, and three two-dimensional abstract images similar in color and shape to the

objects used in testing. In a second experiment, 9-month-olds were exposed to images of an object as well as images of a textured carpet. Across both experiments, infants continued to interact with the images via rubbing, patting, or scratching, but minimal grasping behaviors were observed within both the realistic image and the non-realistic/carpet images. It was concluded that while 9-month-olds tactically explore 2-D images, they perceive them as different from the 3-D objects that they represent. Thus, their interactions with 2-D images are fundamentally different than they are with 3-D objects.

Johnson and colleagues (2012) tested 4-month-olds using eye-tracking during an occlusion task, in which either a 2-D or 3-D object was partially occluded as it passed through a non-mobile occluder. By constructivist accounts, at 4-months representational abilities are still developing and are therefore highly susceptible to context and stimulus features (Johnson, Bremner, Slater, Shuwairi, Mason, Spring, & Usherwood, 2012). Thus, the goal was to measure how 2-D and 3-D objects influenced perception of trajectory continuity, which is the understanding that the various visual components might comprise a single object. The understanding (or lack of) of object continuity might influence visual expectations for the stimuli as it moves past an occluder object and into full view. Saccade number and latency was recorded to measure anticipatory and reactive saccades. Anticipatory saccades were defined as eye movements to an area 150 ms before object appearance. This area was consistent with the object's movement trajectory and therefore indicated anticipation of the object's appearance and possible understanding of the object as a whole. Eye movements to same area 150 ms post-object appearance were labeled as reactive saccades, and indicated a lack of perception of the object as a whole. The findings indicated that while the amount of anticipatory or reactive saccades did not significantly differ between groups, within the 3-D condition reactive eye movements were

slower and anticipatory eye movements were quicker compared to the 2-D condition. While the authors called attention to the subtlety of these differences and emphasized the interaction of context with underdeveloped perceptual abilities in occluder tasks, it was suggested that the 3-D condition led to increased attention to the object prior to occlusion. This increase in attention, in combination with the additional depth cues inherent to 3-D objects, may have assisted with the formation of mental representations of the images (Johnson et al., 2012). Ultimately, the combination of these various studies across ages and procedures suggest that there are differences in visual processing between 2-D and 3-D stimuli for infants. However, it remains ambiguous as to exactly what factors influence differential processing of 2-D images and 3-D objects in infancy.

Infant ERP Research on Attention and Object Processing

In addition to using behavioral measures, infant cognition is commonly investigated with the use of the electroencephalogram (EEG). The EEG can be analyzed as ERPs, which are scalp-recorded voltage oscillations in the EEG that are time-locked with an event of interest. ERP components are commonly defined by a combination of their functional significance and their waveform morphology (latency, polarity, duration, and location on the scalp) (Picton, Bentin, Berg, Donchin, Hillyard, Johnson, Miller, Ritter, Ruchkin, Rugg, & Taylor, 2000). For the purpose of investigating infant visual attention and recognition memory, the Negative central (Nc) and late slow wave (LSW) ERP components are most relevant.

The Nc component is associated with attention in infancy. Across studies, Nc has been found to be greater in amplitude when the stimulus is comparatively novel or possesses other

attractive visual features such as a mother's face (Carver, Meltzoff, & Dawson 2006; de Haan & Nelson, 1997, 1999; Reynolds et al., 2010; Reynolds & Richards, 2005, 2009). It is most commonly found in central and frontal electrode locations, and is represented as a negative deflection in the ERP waveform with a peak latency from 350-750 ms after stimulus onset (Courchesne et al., 1981; de Haan, 2007; de Haan & Nelson, 1997, 1999; Nelson & Collins, 1991, 1992; Reynolds et al., 2010; Reynolds & Richards, 2005). The Nc ERP component is most commonly interpreted as a reflection of attention engagement (Reynolds, Courage, & Richards, 2010) because research has demonstrated: greater Nc amplitude related to novel stimuli when familiarization occurs in the lab (Courchesne et al., 1981; Reynolds & Richards, 2005), or greater amplitude Nc to highly familiar stimuli from home possessing positive emotional valence for the infant (de Haan & Nelson, 1997, 1999).

The LSW ERP component is associated with infant recognition memory. As infants process a visual stimulus, a decline in amplitude of the LSW occurs across repeated presentations (de Haan & Nelson, 1997; Guy, Reynolds, Mosteller, & Dixon, 2017; Guy, Reynolds, & Zhang, 2013; Nelson & Collins, 1991, 1992; Reynolds, Guy, & Zhang, 2011; Reynolds & Richards, 2005, 2009). The LSW ERP component is examined 1-2 s after stimulus onset, and occurs most commonly at the temporal, central, and frontal electrodes. The LSW can either be positive or negative in polarity depending on the electrode location and other experimental factors (de Haan, 2007; Reynolds et al., 2011). However, the LSW is a reliable indicator of recognition memory as increased exposure to a stimulus has been repeatedly correlated with decreases in LSW amplitude (e.g., de Haan & Nelson, 1997, 1999; Reynolds et al., 2011; Reynolds & Richards, 2005).

Reynolds, Guy, and Zhang (2011) investigated the influence of individual differences in visual attention on ERP correlates of attention and object recognition in infancy. To examine individual differences, 6- and 7.5-month-old infants were split into two looker-type groups (long lookers and short lookers) based on look duration during familiarization. Infants who demonstrate brief fixations during initial exposure to a visual stimulus (short lookers) have been shown to process visual stimuli more efficiently and thus display greater recognition memory for test stimuli than infants who demonstrate relatively long fixations (long lookers; Colombo & Mitchell, 1990; Guy, Reynolds, & Zhang, 2013). The results of Reynolds and colleagues' (2011) indicated that short looking infants displayed greater amplitude LSW to novel than familiar objects indicative of recognition memory of the familiar stimulus. Further, there were no significant differences in LSW amplitude when comparing the novel and familiar presentations for long lookers. These results suggest that short lookers had greater recognition memory for the familiar stimulus as indicated by greater LSW amplitude for novel stimuli, than the less visually efficient long lookers. Therefore, differences in the distribution of selective visual attention during stimulus familiarization appear to have a significant influence on visual processing efficiency and subsequent recognition memory for visual stimuli in infancy.

Effects of Familiarization Procedure on Infant ERP

There is a growing body of research demonstrating that the type of familiarization procedure used in a given study has a significant impact on ERP correlates of attention and recognition memory in infancy. Previous work using an oddball procedure with pictures of two human faces (one picture presented with 80% frequency of presentation and the other presented

with 20% frequency) has demonstrated increased looking time as well as greater Nc amplitude during the more novel (i.e., oddball) stimulus presentations (Courchesne et al., 1981).

Courchesne and colleagues (1981) concluded that not only were infants able to recognize the pictures of faces presented more frequently in an oddball experiment, but also infants were more attentionally engaged with novel face stimuli than familiar. However, since this experimental procedure contains no familiarization condition, this increase in attention engagement could instead reflect detection of a low probability event rather than novelty detection.

Reynolds and Richards (2005) used a modified oddball procedure (Nelson & Collins, 1991) to examine the effects of familiarization conditions on Nc amplitude as well as the LSW. They tested infants at 4.5, 6, and 7.5 months of age. Infants were familiarized to alternated presentations of each of two visual patterns for 5 s of looking until they accumulated 20 s of looking to each stimulus. For testing, infants were split into two groups. The preexposure group was presented with a frequent familiar and an infrequent familiar pattern along with novel pattern presentations, and the control group was presented only with novel pattern presentations. However, within the control group, one novel pattern was presented repeatedly with high frequency and one novel pattern with low frequency. Both groups were presented with twelve additional novel stimuli. Results revealed an interaction of familiarization and stimulus type in Nc amplitude, with the pre-exposure familiarization group demonstrating a greater Nc amplitude to the novel stimuli compared to familiar stimuli. The infants in the control group who had no pre-exposure to the stimuli prior to ERP testing did not demonstrate differences in Nc amplitude based on stimulus type. The greater Nc amplitude to the novel stimuli for the pre-exposure group is likely based on relatively decreased attention to the previously viewed familiar stimuli. To further support the idea that Nc is indicative of attentional engagement, research utilizing heart

rate measurements (Reynolds et al., 2010; Richards, 2003) has shown that Nc amplitude is greatest when heart rate measures are indicative of attention (i.e., a significant decrease in heart rate in comparison to a pre-stimulus baseline).

In contrast to the studies described above, de Haan and Nelson (1997, 1999) tested 6-month-old infants in a series of ERP experiments utilizing photographs of highly familiar stimuli from home and found greater amplitude Nc to familiar compared to novel stimuli. They used a between-groups design where infants were presented with images of either faces or toys. For each group, they included one image of the infant's favorite toy from home or a picture of the infant's mother's face. A dissimilar-looking novel face or novel object image were paired with each familiar face or toy, and the novel and familiar stimuli were presented to the participant randomly and with equal probability. There was larger amplitude of the Nc ERP component for the familiar stimuli for both the face and the object conditions, indicating that the Nc ERP component does not simply reflect novelty detection. Rather, greater attention to a familiar stimulus may occur when the familiar stimuli are meaningful or possess positive emotional valence for the infant. There was also a larger positive-polarity LSW (indicating stimulus encoding) for the novel stimuli for both faces and objects. Taken together, these findings demonstrate that factors related to familiarization have a significant impact on differential amplitude of the Nc component to novel and familiar stimuli.

Carver, Meltzoff, and Dawson (2006) investigated whether testing 18-month-old toddlers in a recognition memory task using either 2-D or 3-D exposure conditions differentially impacts neural correlates of object recognition. The 18-month-olds were tested on their ability to recognize familiar and unfamiliar objects in both 3-D and 2-D, as well as ability to recognize a 3-D stimulus in 2-D picture form. Favorite toys were brought in from home and presented

randomly in 3-D along with an unfamiliar 3-D toy. Toys were presented on a spinning platform inside a box that obscured the other toy, so as to only present one stimulus at a time. For the second experiment, 18-month-olds were split into a 2-D and 3-D condition. Participants were again presented with randomly mixed presentations of a familiar toy from home or novel toy, but this time in either the 3-D condition or a 2-D picture condition. 18-month-olds were able to differentiate their familiar toy from home from the novel toy in both conditions, as indicated by greater Nc to the familiar rather than unfamiliar toys. However, the Nc component amplitude differences between the familiar and unfamiliar toys were only significant within the 2-D group. For the N2 ERP component, a temporally earlier component implicated in exogenous sensory perception, only the 3-D group showed significant differences to indicate differentiation. These results imply that infants in the 2-D condition may have needed more time than those in the 3-D condition to distinguish familiar from unfamiliar stimuli. Therefore, while infants were able to differentiate novel and familiar stimuli in both the 2-D and 3-D conditions, the differences in ERP components across groups indicates differences in early stages of perceptual cognitive processing of the visual stimulus depending on the condition (Carver, Meltzoff, & Dawson, 2006; de Haan & Nelson, 1997, 1999; Reynolds, 2015). The authors did not analyze the LSW as an index of recognition memory in this study.

To directly investigate how previous experience with a stimulus outside of a laboratory setting shapes visual attention and recognition memory, Moulson, Shannon, and Nelson (2011) employed a unique familiarization condition. They had two groups of 2- to 3-month-old participants. The “experience” group consisted of infants at 2 months of age who were exposed to a month of familiarization at home with a 3-D head model on a cart. Caregivers were asked to keep the head model in close proximity to the child for an hour a day. The “no-experience”

group received 1.5 min of familiarization to the 3-D head model at 3 months while at the laboratory. Both groups were then shown 2-D images of both the model head they were familiarized to as well as a novel head models, with equal probability of presentations. The authors found that for the “experience” group, there was greater amplitude Nc in presentations of the familiar head model. Those in the “no-experience” familiarization condition showed greater Nc amplitude to the novel head models. Therefore, both the amount of familiarization time as well as initial exposure in either 2-D or 3-D influenced the relative amplitude of the Nc ERP component to familiar and novel stimuli. Similar to Carver and colleagues (2006), the authors did not analyze the LSW, so potential differences in recognition memory across familiarization groups in this experiment were not examined.

Current Study

The purpose of the current study was to shed light on the effects of familiarization to 2-D or 3-D stimuli on the amplitude of ERP components to novel and familiar stimuli in subsequent testing with 6-month-old infants. Carver, Meltzoff, and Dawson (2006) concluded that efficiency of processing is greater in 3-D conditions than 2-D among highly familiar objects. However, their findings were not fully conclusive, and they did not analyze the LSW as an index of recognition memory. Additionally, their use of 18-month-olds makes it difficult to generalize their findings to the vast majority of research on neural correlates of infant attention and recognition memory which has tested infants at approximately 6 months of age (de Haan & Nelson, 1997, 1999; Nelson & Collins, 1991; Reynolds, Courage, & Richards, 2010, 2013; Reynolds & Richards, 2005; Snyder, 2010, Snyder, Garza, Zolot, & Kresse, 2010; Snyder, Webb, & Nelson, 2002).

Moulson, Shannon, and Nelson (2011) directly investigated how previous experience with a stimulus outside of a laboratory setting shapes visual attention and recognition memory, but their use of 2- to 3-month-old infants again raises concerns with generalizability of their findings to later infancy. Additionally, the familiarization condition used in their study was not well controlled, and they did not analyze the impact of familiarization on the LSW and recognition memory. Thus, it is not clear whether the differential effects of familiarization procedure on Nc amplitude were paired with effects on visual processing and subsequent recognition memory. Therefore, the current study aimed to address a gap in the existing literature by testing 6-month-old infants using either a 2-D or 3-D familiarization procedure in a controlled laboratory setting followed by recognition memory testing using 2-D photographs of novel and familiar objects in a traditional ERP approach (de Haan & Nelson, 1997, 1999; Nelson & Collins, 1988; Reynolds & Richards, 2005; Reynolds, Courage, & Richards, 2010; Reynolds, Guy, & Zhang, 2011). This study also examined potential relations between attentional engagement, visual processing, and recognition memory of 2- and 3-D stimuli through analyzing both the Nc and LSW ERP components.

Along with connecting previous literature, 6-month-old participants were tested because this age captures a developmental period where many new functionalities are developing. At 6-months of age the posterior orienting system has developed significantly, allowing for increased efficiency of visual processing (Colombo, 2001; Posner & Peterson, 1990), as well as an interaction between looking preferences and complexity of presented stimuli (Courage, Reynolds, & Richards 2006). Also, there are major gains in attention and exploration of objects as reaching and grasping develops from 3-5-months (Gibson, 1978; Williams, Corbetta, & Guan, 2015), and infants become increasingly object oriented with the onset of reaching abilities

(Reynolds, 2015). With all of these advancements in abilities and changes in attention, 6-months is an ideal age to examine 2-D and 3-D object familiarization as it relates to attention and memory.

Previous research has demonstrated that 6-month-olds demonstrate greater amplitude Nc to highly familiar stimuli from home compared to novel stimuli (de Haan & Nelson, 1997, 1999), and greater amplitude Nc to novel stimuli in comparison to stimuli they are familiarized with prior to testing in laboratory settings (Reynolds & Richards, 2005). Based on these findings, in this study it was hypothesized that within the 2-D familiarization group, 6-month old infants would demonstrate greater Nc amplitude for novel stimuli compared to familiar. Within the 3-D group, it was predicted that infants would show greater Nc amplitude to the familiar stimulus compared to the novel, as initial exposure to the stimulus in 3-D would lead infants to continue attending to the more complex 3-D stimuli for further processing during testing.

LSW amplitude was also analyzed to provide insight into potential effects of 2-D and 3-D familiarization on visual processing and subsequent recognition memory of the familiar stimulus. It was hypothesized that within the 2-D familiarization group, the LSW would be greater in amplitude for the novel stimuli compared to the familiar indicative of recognition memory. However, in the 3-D familiarization group it was predicted that the LSW would not differ in amplitude between the familiar and novel presentations. For the 3-D familiarization group, the predicted lack of difference in LSW amplitude across familiar and novel stimuli paired with greater Nc amplitude to the familiar stimulus would reflect partial (i.e., incomplete) visual processing of the more complex 3-D stimulus.

CHAPTER II

METHODS

Participants

The final dataset included 35 Caucasian infants and 1 Hispanic infant (21 males, 14 females). Infants were recruited for this study from the Child Development Research Group participant database at the University of Tennessee, and were tested within two weeks of their 6-month birthdate. Only infants born full-term (no less than 38 weeks gestation) without complications and no known health issues were tested. Participants were recruited without regard to race, ethnicity, or gender. Additional infants were tested but excluded due to familiarization time of less than 15 s ($N = 19$), fussiness ($N = 6$), inadequate number of trials ($N = 5$), technical issues ($N = 12$), or experimenter error ($N = 1$).

Infants were randomly split into the 3-D and 2-D conditions prior to testing. Of the infants included in the final dataset, 18 infants were included in the 3-D group and 17 infants were included in the 2-D group. Of the infants in the 3-D group, 7 were familiarized to object 1, and 11 were familiarized to object 2 (see description of the objects below). Of the infants in the 2-D group, 8 were familiarized to object 1, and 9 to object 2.

Visual Stimuli

The familiar stimulus consisted of either an actual 3-D object situated on a clear plastic stand (see Figure 1) or a 2-D bitmap picture of an object displayed on the computer monitor (see Figure 2). Objects were selected from the NOUN (Novel Object Unique Names) database (Horst

& Hout, 2015), which consists of pictures of a variety of objects of similar size and complexity that participants are unlikely to have had prior exposure to. Included were household objects or toys which have had parts removed or rearranged in unique configurations. Examples of select objects are a folded Jacob's Ladder toy, a teething ring with a segment of the ring removed, and a rubber centipede toy tied into a knot. All objects were presented with a white background and were controlled for size. All of the 45 objects in the NOUN database had the possibility of presentation during testing. Two objects (object 1 and object 2) were selected from the database for familiarization in both the 2-D and 3-D familiarization phase (see Figure 1 for 2-D bitmap versions of object 1 and object 1) in order to ensure that no effects found were driven by properties of a specific object. Additionally, the same two objects were used across familiarization conditions. Both object 1 and object 2 were approximately four inches high in both the 2-D and 3-D presentation conditions.

Apparatus

Once an infant was recruited and arrived at the laboratory, informed consent from the guardian was obtained, and the infant's head measured to select the appropriately sized Electrical Geodesic, Inc. (EGI; Eugene, OR) sensor net. The infant sat on their guardian's lap facing and approximately 55 cm away from a display monitor (27 inch color liquid crystal display [LCD]; Dell 2707 WFP). A digital camcorder (Sony DCR-HC28) used to judge visual fixations was located above the center of the presentation monitor. Once the infant was seated, the EGI sensor net was applied.

The EGI system uses high-impedance amplifiers connected to a computer A/D card in a

PowerPC-based computer system. Netstation software (Electrical Geodesics Incorporated [EGI]) on a Mac OS desktop was used to record EEG data that is synchronized with the digital camcorder. It was also temporally synchronized using E-Prime 2.0 software (Psychology Software Tools, Inc.; Sharpsburg, PA) on a Dell Workstation computer. The E-Prime program controlled stimulus presentations on the computer monitor in the experimental room as well as the Net Station. Eprime and Net Station had a single-clock system in order to time lock experimental events between the video data and the EEG.

Procedure

Testing occurred in two phases. First, infants completed the familiarization phase, and then the ERP testing phase began. For the familiarization phase, participants were exposed to 20 s of accumulated looking to the familiar stimulus. Exposure consisted of either a 2-D bitmap image of an object that appeared on the monitor, or a 3-D object placed on a clear plexiglass stand placed immediately in front of the monitor. For the 3-D condition, the familiarization object was positioned on the plexiglass stand immediately in front of the presentation monitor (see Figure 2), and situated on the stand in as close to the same orientation as the object was shown in the 2-D photograph used for familiarization in the 2-D condition and ERP testing. The plastic stand was positioned in front of the monitor for familiarization to 2-D objects for constancy across conditions (see Figure 3). A floor lamp was illuminated and placed behind the infant for better illumination of the object for the 3-D familiarization condition. The lamp was also used during 2-D familiarization trials for the sake of constancy across conditions. After familiarization, the familiarization object was immediately removed from either the stand or the monitor depending on familiarization condition, the stand was removed, and the lamp and

overhead lights were turned off to eliminate distractions during ERP testing. During the ERP phase, the participant was exposed to repeated presentations of 2-D bitmap images of the familiar object and 2-D bitmap images of novel objects. Novel and familiar object stimuli were presented with equal probability in pseudo-random order. The duration of stimulus presentations was 500 ms for each presentation. Each stimulus presentation was followed by a blank screen that varied in duration randomly from 1500 – 2000 ms. Testing typically lasted about 10 m, and was continued until the infant showed signs of fatigue/fussiness or was no longer on task.

EEG Recording

EEG data was collected using a 128-channel infant-sized sensor net (HydroCel Geodesic Sensor net) connected to NetAmps hardware. The NetAmps hardware was also connected to Mac OS desktop computer with Netstation recording program software that is synched with the video feed. This package of equipment comprises the Electrical Geodesics Incorporated (EGI) Geodesic EEG System 300 (GES 300) recording system. The EEG cap has a total of 124 EEG electrodes housed within soft sponge pedestals and connected by thin elastic bands within. The cap was positioned on the infant with guidance from the marked central Cz electrode, which is positioned on the vertex, as well as pedestals marked for placement on the left and right mastoids.

The geodesic configuration of the elastic sensor net served to hold the remaining electrodes in properly positions after proper placement of the Cz and mastoid electrodes. The nets were adjusted until the majority of electrode impedances ranged from 10 – 50 k Ω . Infant looking during testing was recorded using the Sony camcorder and analyzed offline to insure the

infant was looking during experimental trials. Any trial in which the infant was judged to be looking away from the monitor during stimulus presentation was excluded from further analysis. The EEG recording had a sampling rate of 250 Hz, a band-pass filter set from 0.1 – 100 Hz during recording, and 20K amplification. After recording, EEG files were run through a 0.3 – 30 Hz bandpass filter.

EEG Analysis

To remove artifact from EEG recordings, channels with waveform fluctuations greater than 250 μV /250 ms or poor recording were marked bad. Trials with greater than 10% of electrodes marked bad or trials in which the infant was not centrally fixated during stimulus presentation were excluded from further analysis. On remaining trials, individual channels marked bad were replaced using a spherical spline interpolation (Perrin, Pernier, Bertrand, Giard, & Echallier, 1987; Srinivasan, Tucker, & Murias, 1998). Only those participants who contributed enough ERP trials per condition (i.e., at least 8 trials) for stable ERP averages following EEG editing were included in the final dataset. On average, infants contributed 18.69 trials (range: 8 – 37) in the familiar condition, and 18.91 trials (range: 8 - 34) in the novel condition. Individual averages were then computed for the novel and familiar condition for each participant. The averaged ERP files were re-referenced to the average reference, and baseline corrected using the 200 ms preceding stimulus onset as the baseline period.

To allow for the analysis of the Nc and LSW ERP components, the ERP was segmented from 200 ms prior to stimulus onset through 2 s post stimulus onset. Electrode clusters were analyzed from 450 - 750 ms post stimulus onset for Nc mean amplitude, and the LSW was

analyzed as the mean amplitude of the ERP from 1 - 2 s post stimulus onset. Determination of electrode clusters for each ERP component were determined based on previous research (de Haan & Nelson, 1997, 1999; Reynolds et al., 2005, 2010, 2011, 2017) and visual inspection of the grand average waveforms as is standard practice in the field (DeBoer, Scott, & Nelson, 2007). For the Nc analysis, clusters of electrodes from left frontal (20, 24, 27, 28), right frontal (117, 118, 123, 124), and midline central areas (6, 7, 13, 106, 112) were examined. For the LSW analysis, clusters of electrodes from left anterior temporal (35, 36, 41), midline central (ref, 7, 106), right anterior temporal (103, 104, 110), and midline parietal (61, 62, 78) were examined. For inclusion in the dataset, participants had to have completed a minimum of 15 s of accumulated looking to the object during familiarization, and infants had to contribute at least 8 ERP trials for both the familiar and novel testing conditions.

Statistical Analysis Design

This study had a 2 x 2 mixed design with familiarization condition (2: 2-D, 3-D) as a between-subjects factor and stimulus type (2: novel, familiar) as a within-subjects factor. Electrode location served as an additional within-subjects factor which varied in level based on the ERP component being analyzed. Thus, 3-way repeated-measures ANOVAs were used for the analysis, and post hoc multiple comparisons were done using 2-way repeated-measures ANOVAs separately by exposure condition. Effect sizes are reported using η_p^2 , and the alpha level was set at .05 for all tests.

CHAPTER III

RESULTS

Nc Component

A repeated measures ANOVA was conducted with stimulus type (2: novel, familiar) and electrode location (3: left frontal, right frontal, midline central) as within-subjects factors, and familiarization condition as a between subjects factor (2: 2-D, 3-D). There was a significant interaction between stimulus type and familiarization condition, $F(1, 33) = 6.394$, $p = .016$, $\eta_p^2 = .162$ (see Figure 4). Post-hoc analysis revealed infants in the 2-D familiarization condition demonstrated significantly greater amplitude Nc ($p = .011$) to novel stimuli ($M = -4.781$, $SE = 1.280$) in comparison to the familiar stimulus ($M = -1.306$, $SE = 1.310$). In contrast, infants in the 3-D familiarization condition demonstrated greater amplitude Nc to familiar ($M = -3.770$, $SE = 1.214$) compared to novel stimuli ($M = -2.782$, $SE = 1.012$); however, this difference was not statistically significant, $p = .45$.

LSW Component

In order to analyze the LSW, a repeated measures ANOVA was conducted with stimulus type (2: novel, familiar) and electrode location (4: left central, midline central, right central, and midline parietal) as within-subjects factors, and familiarization condition as a between subjects factor (2: 2-D, 3-D). There was a significant main effect of stimulus type, $F(1,33) = 4.776$, $p = .036$, $\eta_p^2 = .126$ (see Figure 5). Across familiarization conditions and electrode locations, infants

demonstrated greater amplitude positive slow waves to the novel ($M = 13.181 \mu\text{V}$; $SE = .989$) than the familiar stimuli ($M = 10.054 \mu\text{V}$; $SE = 1.341$).

CHAPTER IV

DISCUSSION

The current study examined the effects of controlled, in-lab familiarization with either 2-D or 3-D objects on neural correlates of attention and recognition memory in 6-month-old infants. Participants were familiarized to either a 3-D object or a 2-D bitmap image of an object for an accumulated 20 s of looking. During the test phase of the experiment, participants were shown 2-D bitmap images of either the familiar or novel objects. It was predicted that infants would demonstrate increased Nc amplitude for the novel stimuli compared to familiar in the 2-D familiarization condition, and greater Nc amplitude to the familiar stimulus compared to the novel in the 3-D familiarization condition. Also, LSW amplitude was expected to be greater in amplitude to the novel compared the the familiar stimuli in the 2-D condtion, but not differ between novel and familiar in the 3-D condition.

However, the results only partially supported these hypotheses. As predicted, infants in the 2-D familiarization group demonstrated significantly greater amplitude Nc to novel stimuli in comparison to the familiar stimulus. This indicates increased attention for the novel stimuli in the 2-D familiarization group (see Figure 4). In the 3-D familiarization group, although the average amplitude of Nc was greater to familiar than novel stimuli, the difference was not significant. As can be seen in Figure 5, the results of the LSW analysis indicate that both familiarization groups fully processed and recognized the familiar stimulus as the LSW was greater in amplitude to the novel stimuli within both the 2-D and 3-D conditions.

Taken together, these findings suggest that the observed differences in Nc amplitude and attention are not based on inadequate processing of the familiar stimulus for infants in the 3-D

condition. While the significant interaction of familiarization condition and stimulus type indicates that attention patterns varied across groups, both groups demonstrated evidence of recognition memory for the familiar object. Thus, object dimension did not appear to have a significant influence on visual processing and subsequent recognition memory for the familiar stimulus in the current testing context. The results do indicate that familiarization condition had differential effects on infant attention, and thus shifted the salience hierarchy of familiar and novel stimuli in subsequent testing.

The current findings are not consistent with previous studies in which the familiar stimulus was highly familiar to the infant. In de Haan and Nelson's study (1999) 6-month-old infants were presented with pictures of highly familiar 3-D stimuli, and they found higher amplitude Nc for the familiar stimuli compared to novel stimuli. For Carver and colleagues' (2006) work comparing toys from home with novel objects, again a greater amplitude Nc was demonstrated for the familiar toy from home. Moulson and colleagues' (2011) study further demonstrated that greater Nc amplitude to familiar stimuli can occur even when the highly familiar stimulus is an inanimate head model with whom the participants did not physically interact. The results from the current study do not perfectly align with the Nc patterns found in these three studies. However, consistent with work in which the infant was familiarized to the stimulus for a relatively short period of time within a laboratory (e.g., Reynolds and Richards (2005); Courchesne et al., 1981), exposure to the familiar stimulus in 2-D led to significantly greater attention (as indicated by Nc amplitude) to novel compared to familiar stimuli, and this effect on attention was not found for the 3-D familiarization group. These differences in attention across groups cannot be explained as due to inadequate processing of the object in the

3-D condition since infants in both familiarization groups showed significantly greater amplitude LSW to the novel compared to familiar stimuli indicative of recognition memory.

While Pierroutsakos and DeLoache (2003) concluded that infants have difficulty with pictorial competence and thus interact with 2-D images in a similar manner to 3-D objects. Yonas and colleagues (2005) disagree with the conclusion that infants do not have pictorial competence and thus interact with 2-D images as if they are 3-D objects. Consistent with the position of Yonas and colleagues (2005), the results of the current study indicate there are differences in how infants attend to 2-D stimuli in comparison to 3-D stimuli. This finding is also consistent with previous research showing that infants attend to 2-D and 3-D stimuli differently across various familiarization procedures and age groups (Carver et al., 2006; Johnson et al., 2012; Moulson et al., 2011; Yonas et al., 2005). However, the current analysis of the LSW indicates these differences in attention are not based on differences in the ability of infants to visually process information provided in 2- versus 3-D conditions. Infants in both familiarization conditions demonstrated recognition memory for the familiar stimulus as indicated by greater amplitude positive slow waves to novel stimuli in comparison to the familiar stimulus.

Limitations and Future Research

There are some limitations to the current study worth noting. For example, the LSW is a general measure of recognition memory. In light of the attentional differences across conditions, tests of other types of memory may have revealed differences across groups. Future work could continue to probe the impact of attention on visual processing through the use of increasing delays between familiarization and testing. A study utilizing this approach may reveal long term

memory differences across initial exposure conditions. Alternatively, future research could also investigate the effects of shortened familiarization times as a means with which to examine the possibility that infants might encode information more efficiently in either 2-D or 3-D presentations.

Another potential avenue of study would be to modify the current procedure to allow the participant to interact freely with the 3-D object during familiarization. It is possible that initial exploration that includes haptic feedback would modify visual processing, attention, and memory outcome (Johnson, Amos, & Slemmer, 2003; Soska, Adolph, & Johnson; 2010). For example, research with 4.5 – 7.5-month-old-infants tested their abilities to mentally complete partially occluded 3-D objects after familiarization (Soska, Adolph, & Johnson; 2010). Motor abilities were assessed before infants were familiarized to simple wedge-objects that contained depth cues on a monitor and then tested on a mental rotation task. Results indicated that the two largest predictors for prediction of the 2-D object with depth cues were higher levels self-sitting experience and coordinated visual-manual exploration. Therefore, future research could utilize an ERP approach similar to the current study while incorporating a familiarization task that includes both visual and haptic information to explore relations between infant motor development and object processing.

Summary of Conclusions

Ultimately, it can be concluded that familiarization within the 2-D condition resulted in greater attention to later presentations of novel stimuli compared to the familiar, as indicated by greater Nc amplitude to the novel stimuli. However, this effect on infant visual attention was not found within the 3-D familiarization group. These results support previous work that has found

differences in infants' responsiveness to 2-D and 3-D stimuli (Carver, Meltzoff, & Dawson, 2006; Johnson et al., 2012; Pierroutsakos & DeLoache, 2003; Ruff, Kohler, and Haupt, 1976). Since both familiarization groups in the current study demonstrated greater LSW amplitude to novel compared to familiar stimuli, it appears that these differences in attention are not based on inadequate visual processing in one familiarization condition compared to the other. Instead, stimulus dimension appears to differentially affect infant visual attention through influencing the salience hierarchy of familiar and novel stimuli during initial exposure. Further study is needed to elucidate what specific factors are driving these differences in attention, and how these differences might influence other cognitive systems. A number of contextual factors, including familiarization procedure and stimulus type, were found to have a significant impact on attention, perceptual processing, and recognition memory in infancy in the current study; providing further insight into the complex nature of processes involved in early perceptual and cognitive development.

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APPENDIX



Figure 1. Bitmap images of familiarization object 1 (left) and object 2 (right). Both objects measured approximately 4 inches in both the 2-D and 3-D conditions.



Figure 2. 3-D stimulus presentation using object 2. The object was placed on top of a clear plexiglass stand that was affixed to the monitor stand, which allowed for the object to be placed in the center of the display monitor.



Figure 3. 2-D stimulus presentation using object 2. The image on the monitor appears to almost rest on a clear plastic stand that is affixed to the monitor stand. The 2-D bitmap image display of the object is presented in the center of the monitor screen.

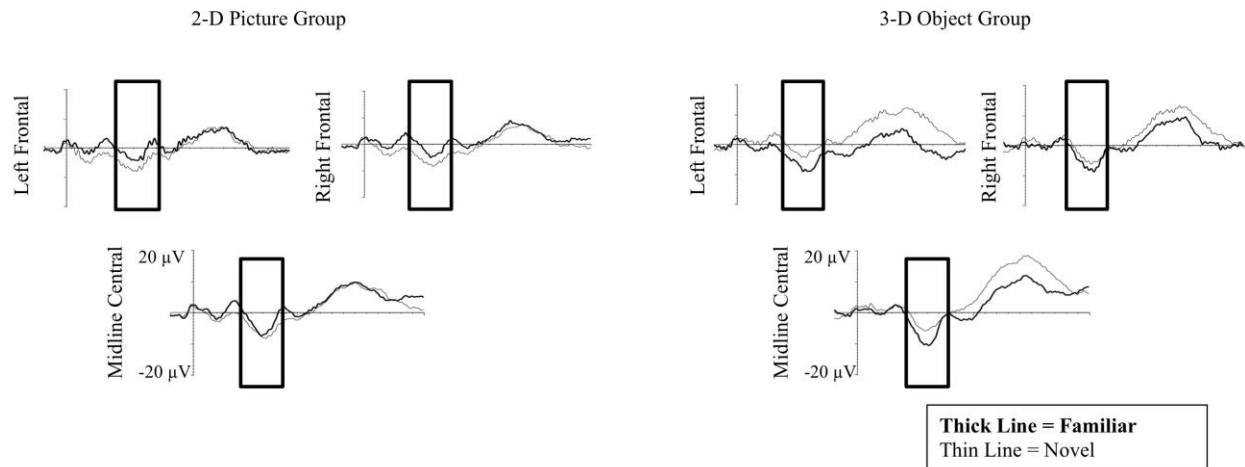


Figure 4. ERP amplitude for significant interactions for Nc waveforms comparing responses to familiar (thick line) and novel (thin line) stimuli by familiarization condition. Boxes indicate the timing of the portion of the waveform examined for Nc analysis. The X-axis is representative of timing post-stimulus presentation and the Y-axis represents waveform amplitude change from baseline (in microvolts).

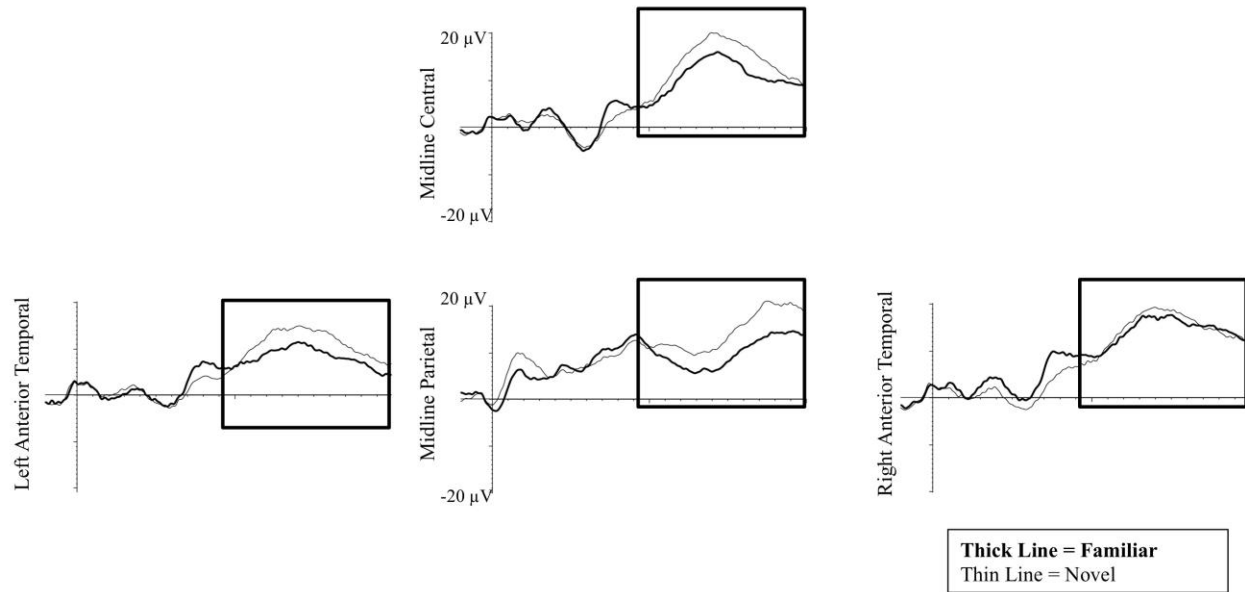


Figure 5. Grand average waveforms demonstrating the main effect for the LSW comparing responses to familiar (thick line) and novel stimuli (thin line). Boxes indicate the portion of the waveform examined for LSW. The X-axis is representative of timing post-stimulus presentation and the Y-axis represents waveform amplitude as it changes from baseline.

VITA

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